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Enhanced Strength and Ductility of AZ80 Magnesium Alloys by Spray Forming and ECAP Techniques

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Abstract

Fast spray forming technology followed by equal channel angular pressing (ECAP) was employed to obtain a specific microstructure: separated coarse magnesium grains surrounded by deformation networks. The deformation layer consisted of ultrafine grained magnesium with an average grain size of 0.6 μm and ellipsoidal shaped β-$Mg_{17}Al_{12}$ particles with a size of 200-300 nm and a volume fraction of 13%. Mechanical tensile test demonstrates the advantage of the specific structure: a yield strength of 235MPa combined with an elongation to failure of 14%.

Keywords: magnesium alloy, spray forming, ECAP, strengthening, deformation mechanisms

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1. Introduction

The AZ series magnesium alloys demonstrated vast continuous eutectic β-$Mg_{17}Al_{12}$ phase precipitation and formation of network-shape texture along matrix grain boundaries during casting [1]. It was shown, that spray-forming technology could overcome the problems produced in conventional casting techniques [2]. It has been demonstrated that equal channel angle pressing/extrusion (ECAP) processing is an effective technique to refine microstructure and homogenize the multiple phases [3]. Thus, the combination of ECAP procession and spray forming technology is promising in endowing the magnesium alloys with better properties.

2. Methods

The AZ80 magnesium alloys prepared by casting and fast spray forming were subjected to ECAP procession with route Bc at the temperatures of 350, 250 and 200°C for two passes, respectively. Simultaneously, systematic microstructure studies on the *ED*, *FD*, and LD were carried out. The Vickers micro-hardness and tensile properties were tested.

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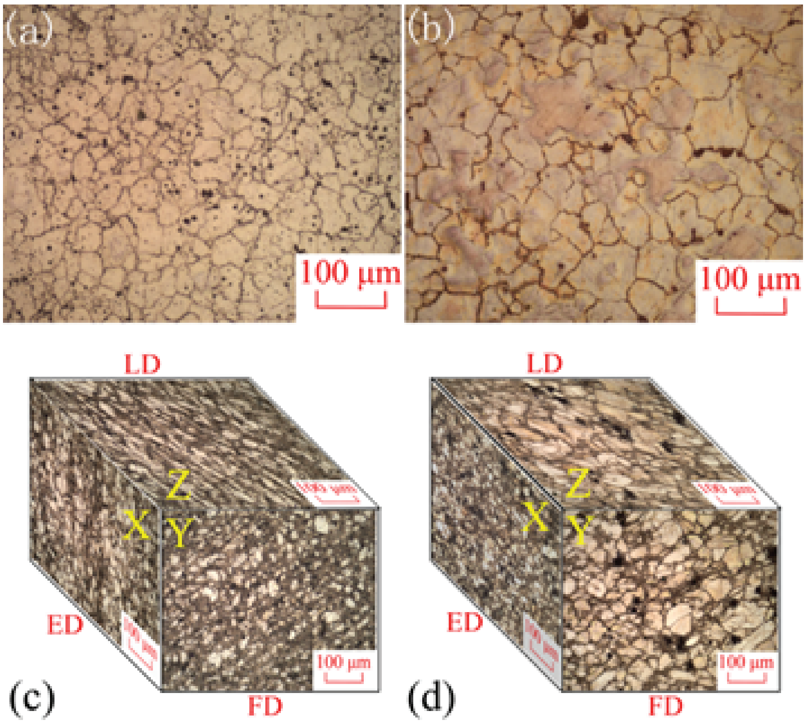

Figure 1: Initial optical micrographs of (a) the as-spray and (b) the as-cast AZ80 alloys; optical micrographs of the extrusion direction (ED), flow direction (FD), and longitudinal direction (LD) of (c) as-spray-ECAP and (d) as-cast-ECAP AZ80 alloys.

3. Results

The optical microscopic observations on the original as-spray and as-cast samples are shown in Figs. 1a,b. The grain size of the as-spray and as-cast samples, measured using an average linear intercept method, are around 40 and 60 μm. It is seen that in the as-spray sample there are spherical precipitates with a diameter of several micrometers at both grain boundaries and grain interiors and some smaller particles, arising in the grain interiors. For the as-cast sample, the grain interiors are clean and large precipitates formed along the grain boundaries. Figs. 1c,d depict the optical metallographic images of the as-spray-ECAP and as-cast-ECAP samples, respectively, in different directions of ED, FD, and LD. Both samples exhibit bimodal structures: coarse separated magnesium grains surrounded by deformation networks with ultrafine grains. The coarse grains in the as-spray-ECAP samples are much smaller than those in the as-cast-ECAP sample, which are in turn subsequently much smaller than those in the samples without ECAP processing. This suggests that the ECAP grain refinement is more effective for the as-spray sample. It is expected that during extrusion and ECAP at elevated temperatures, deformation network layer is forming at the grain boundaries and thickens with increasing deformation strain, finally forming the bimodal structures. The amount and size of the spherical precipitates with a diameter of several micrometers observed in samples without ECAP seem unchanged after ECAP processing, suggesting that ECAP did not break these large precipitates.

	ED	FD	LD
As-spray	64		
As-cast	57		
As-spray-ECAP	127	115	112
As-cast-ECAP	117	104	103

Table 1: Results of HV0.1 microhardness test with dwelling time of 10s. The each average value was obtained from 25 data with an uncertainty of ±2%.

	As-spray	As-spray-ECAP	As-cast	As-cast-ECAP
YS (MPa)	140	235	100	200
UTS (MPa)	225	305	255	315
Elongation (%)	5	14	12	14

Table 2: Results of tensile test for AZ80 alloy at room temperature: the ultratensile strength (UTS), yield strength (YS), and elongation to failure.

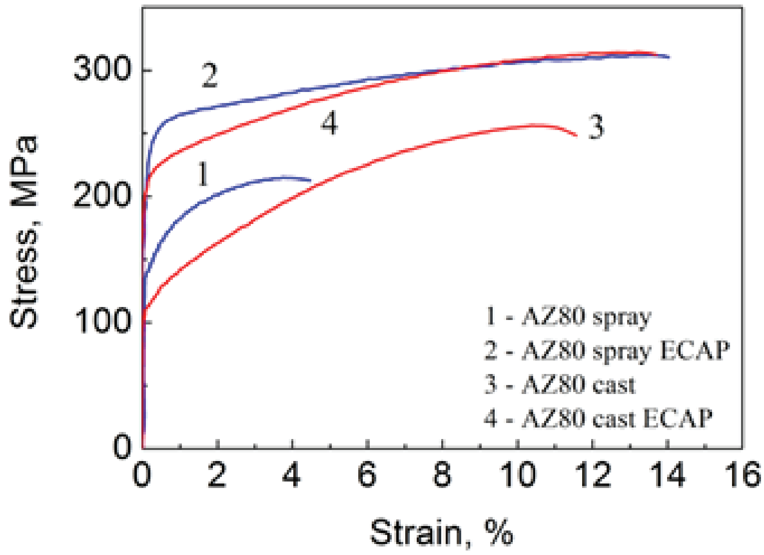

Figure 2: The true stress-true strain curves of the as-spray, as-cast, as-spray-ECAP and as-cast-ECAP AZ80 Mg alloys in the extrusion direction.

The results of HV microhardness test are displayed in Table 1. After ECAP, the HV values (127, 115, and 112 in the ED, FD, and LD for the as-spray-ECAP sample; 117, 104, and 103 in the ED, FD, and LD for the as-cast-ECAP sample) of specimens have been dramatically improved comparing with the original as-spray and as-cast values (i.e., 57HV and 64HV). By contrast, with as-cast-ECAP samples, the HV values of as-spray-ECAP samples are a little larger. Both for as-spray-ECAP and as-cast-ECAP samples, the highest HV value appeared in the FD, followed by samples in ED and LD sequentially. It is worth noting that for the three directions, the results of HV values presented here show identical trend with the mechanical properties of AZ31B alloy [4].

Figure 2 shows the true stress-true strain curves of tensile test. The specific data are displayed in Table 2. The ultra-tensile strength (UTS), yield strength (YS), and fracture elongation of the as-spray-ECAP and as-cast-ECAP specimens are 305 MPa, 235 MPa and 14% and 315 MPa, 200 MPa and 14%, respectively. Compared with the as-spray and as-cast samples, the UTS and fracture elongation of as-spray specimen after ECAP have increased by 45% and 210%, which are 23% and 18% for the as-cast-ECAP. In contrast, the fast spray forming specimens show higher yield strength as compared with casting specimens, being either the as-spray or as-spray-ECAP samples. Notably, the fracture elongation of as-cast alloy is much larger than that of as-spray sample. At the same time the opposite result, obtained after ECAP, verifies that the porosities in fast spray forming samples does decrease during ECAP procession.

4. Conclusion

In summary, ultra-fine grains and great improvement of mechanical properties are obtained after ECAP processing. For the fast spray forming samples, the ultra-tensile strength of 315 MPa and fracture elongation of 14% are obtained simultaneously. It can be concluded that the combination of ECAP processing and fast spray forming technology can dramatically improve the mechanical properties of AZ80 magnesium alloys.

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